

## 6.0 SPRING TRANSITION (APR-MAY)

### 6.1 General Description

During the Spring Transition season, there is a rapid increase in incoming solar radiation as the sun's nadir moves into the Northern Hemisphere. Continental high-pressure zones at the surface weaken and become low-pressure areas (heat lows); upper-level anticyclones form over the surface heat lows as successively higher levels are warmed. Concurrently, the northern Near-Equatorial Trough tends to follow the sun's nadir northward and gradually replaces the weak low-level anticyclone over the Central Arabian Sea. As a result of these circulation changes, low troposphere winds become light and quite variable early in the period (April). By late May, the pressure gradients have reversed from the winter pattern and wind directions typical of the summer (Southwest Monsoon) season predominate. Wind speeds are generally light except near the northern African Coast where the low-level Somali Jet (see Section 3.3.1) starts to appear.

Except in the immediate vicinity of the Near-Equatorial Trough and around tropical storms, skies are generally clearer and visibilities better than during the winter. Tropical cyclones become the main severe weather producers during the Spring Transition -- particularly as the Near-Equatorial Trough advances north of  $5^{\circ}\text{N}$ . In May, a significant number of tropical systems move westnorthwest across the Arabian Sea toward the Arabian Peninsula.

Sea heights during the Spring Transition period are usually moderate except off the northern African Coast in late May and around the more intense tropical systems. Significant heights of 10 ft may be found off Somalia by the end of this Transition Period, and heights in excess of 15 ft are common around the tropical storms.

The mosaic cloud picture shown in Figure 6-1 reflects the generally good weather which is typical of this period. No tropical systems are occurring in the Arabian Sea, but a late-season cyclone is shown near  $10^{\circ}\text{S}$ ,  $75^{\circ}\text{E}$ . A weak extratropical disturbance can be seen approaching the northern Persian Gulf.



Figure 6-1. NOAA visual mosaic showing a typical cloud pattern for the Spring Transition when winds are usually light and skies are mostly clear. Any cloud development seen indicates some form of disturbance. The clouds over the northern Persian Gulf and the central Arabian Peninsula are caused by a trough or weak front. The transition seasons are the favored periods for tropical cyclone development in the northern Indian Ocean, and the cloud mass in the southern Bay of Bengal is a tropical cyclone in the early stages of development. A well-developed tropical cyclone is shown in the Southern Hemisphere near  $10^{\circ}\text{S}$ ,  $75^{\circ}\text{E}$ . Several areas of strong convective activity are seen in the image, e.g., over the southern slopes of the Himalayas, equatorial Africa and Southeast Asia. Weaker activity is seen over southern India and the southwestern portion of the Arabian Peninsula. Convective clouds are common over coastal mountain ranges during this season. Light wind conditions are substantiated by: (a) the weakness or total absence of cirrus plumes from the convective cloud areas (light wind conditions at upper levels), (b) the absence of low-level clouds over the water (light low-level winds), and (c) the narrow sunglint pattern over the eastern Arabian Sea (smooth seas and implied light surface winds). The northern Near-Equatorial Trough is not well-defined in this image; the convective area off the coast of Somalia probably marks the western portion. This trough is most likely to be found near a line from that point to the southern edge of the developing cyclone in the Bay of Bengal.



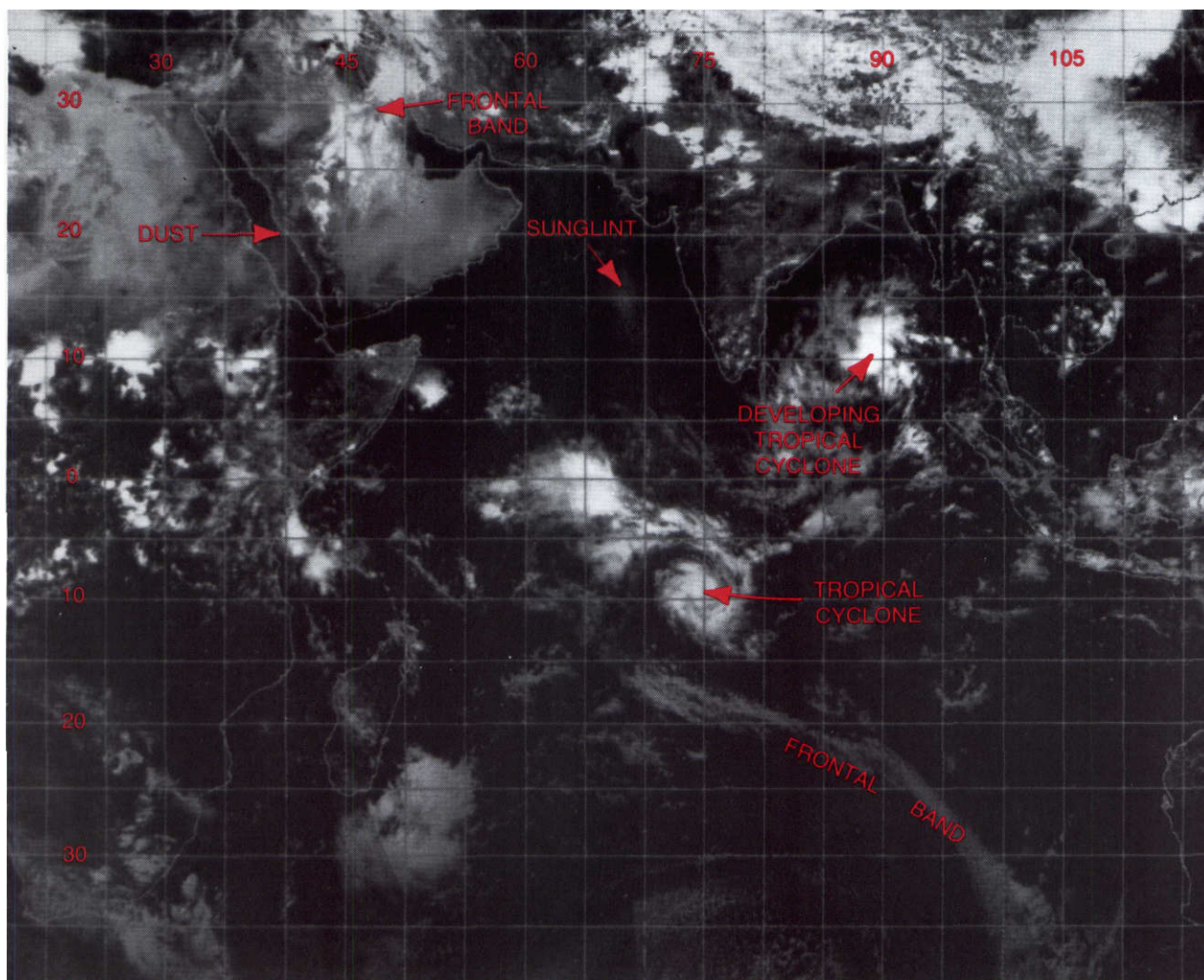


Figure 6-1. NOAA visual mosaic produced from data recorded on April 27, 1982 showing a typical cloud pattern for the Spring Transition period.



## 6.2 Large-Scale Circulation Features

During this period the upper-level Subtropical Ridge moves northward to a mean position between  $12^{\circ}\text{N}$  and  $15^{\circ}\text{N}$ , and strengthens. An upper-level anticyclone forms (in the mean flow) over Indo-China. (This mean anticyclone drifts to a position over Tibet during the Southwest Monsoon.) The resulting high-troposphere flow pattern over the Arabian Sea is weak and rather variable from day-to-day. Westerlies persist north of about  $15^{\circ}\text{N}$  and extratropical disturbances continue to influence the Arabian Peninsula and nearby areas. Weak cross-equatorial flow toward the Southern Hemisphere provides upper-level divergence favorable for tropical cyclone development. Weak vertical wind shear favors convective activity, and other prerequisites for tropical storm development are satisfied when the northern Near-Equatorial Trough migrates to a position north of  $5^{\circ}\text{N}$ . This usually occurs early in the transition period.

Low-level circulation changes of primary importance are caused by gradual intensification of heat lows over the continents bordering the Arabian Sea. The developing heat lows over the Arabian Peninsula and southern Asia gradually reverse the pressure gradient. The northward migration of the dual Near-Equatorial Troughs results in strengthening cross-equatorial flow toward the north near the equatorial east coast of Africa (Somali Jet). These changes result in a clockwise gyre of low-level flow in the Arabian Sea which is the precursor of the Southwest Monsoon. Mid-troposphere subsidence usually suppresses convection (and other cloudiness) over the Arabian Sea north of the Near Equatorial Trough until late May or early June.

### 6.2.1 Climatology

Naval Oceanography Command climatological publications (see Appendix A) should be consulted for information on monthly mean values of operationally significant parameters. The information which follows in Figures 6-2a through e is intended to illustrate the discussion in this section without duplicating those publications.

Of particular significance are the weakness of the winds and the low ocean waves. Although part of the reason is the averaging process, wind speeds at all levels approach an annual minimum during this season. Convective activity, whether found in the Near-Equatorial Trough or over prominent terrain, is noteworthy during the Spring Transition period. Figures 6-2c through e all reflect contour maxima related to convective cloudiness.



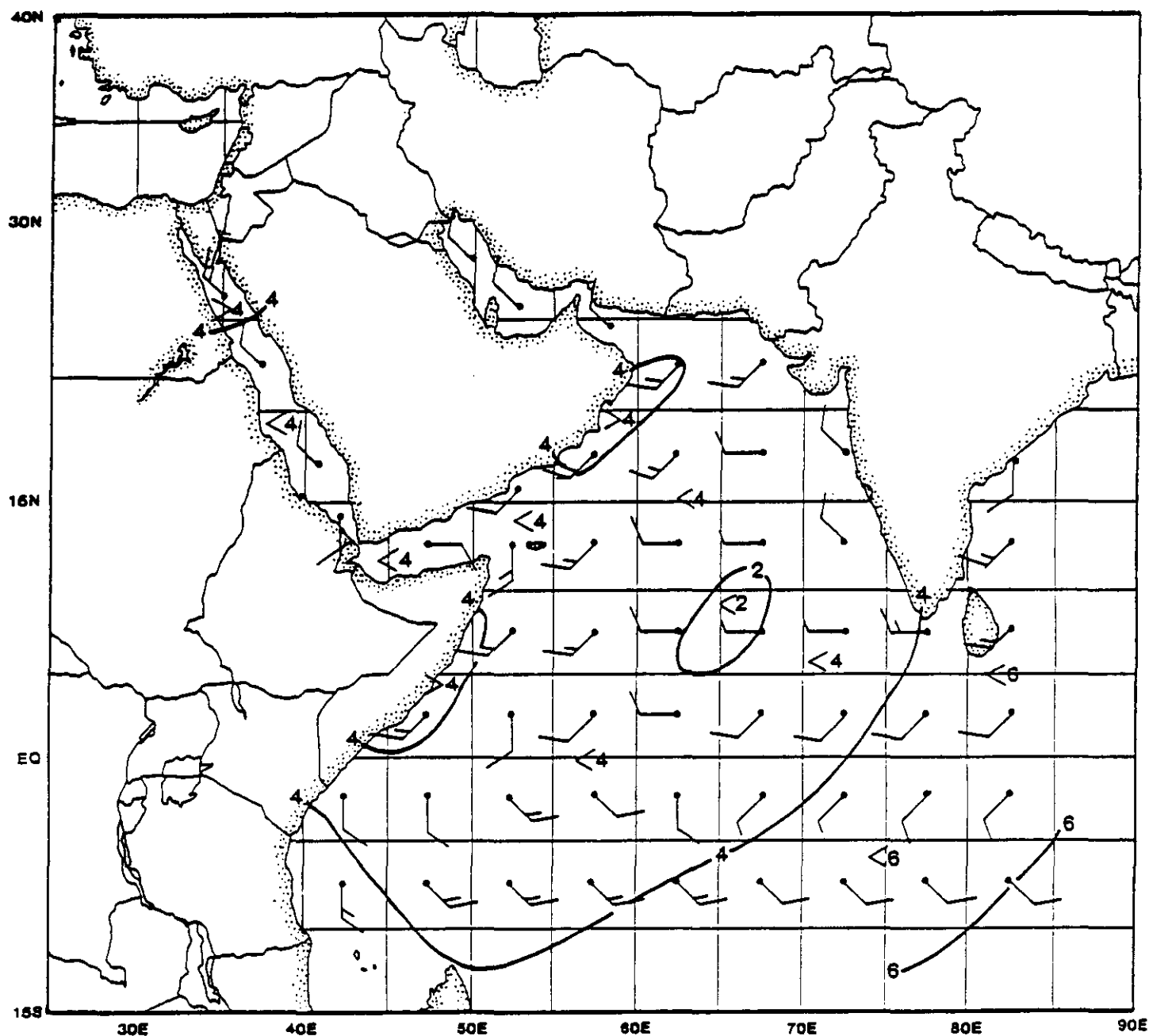


Figure 6-2a. Mean May surface winds (wind barbs) and seasonal mean significant wave heights in ft (contours) (adapted from Naval Weather Service Detachment, Asheville, 1974). The wind barbs represent the average over a 5° rectangle of latitude and longitude. Wind barbs representing the restricted waters of the Red Sea, Persian Gulf and Gulfs of Aden and Oman are plotted over the water area that they represent. The data from which the contours of significant wave height were determined represents only the highest of the observed heights when both a wind wave group and a swell group were reported.



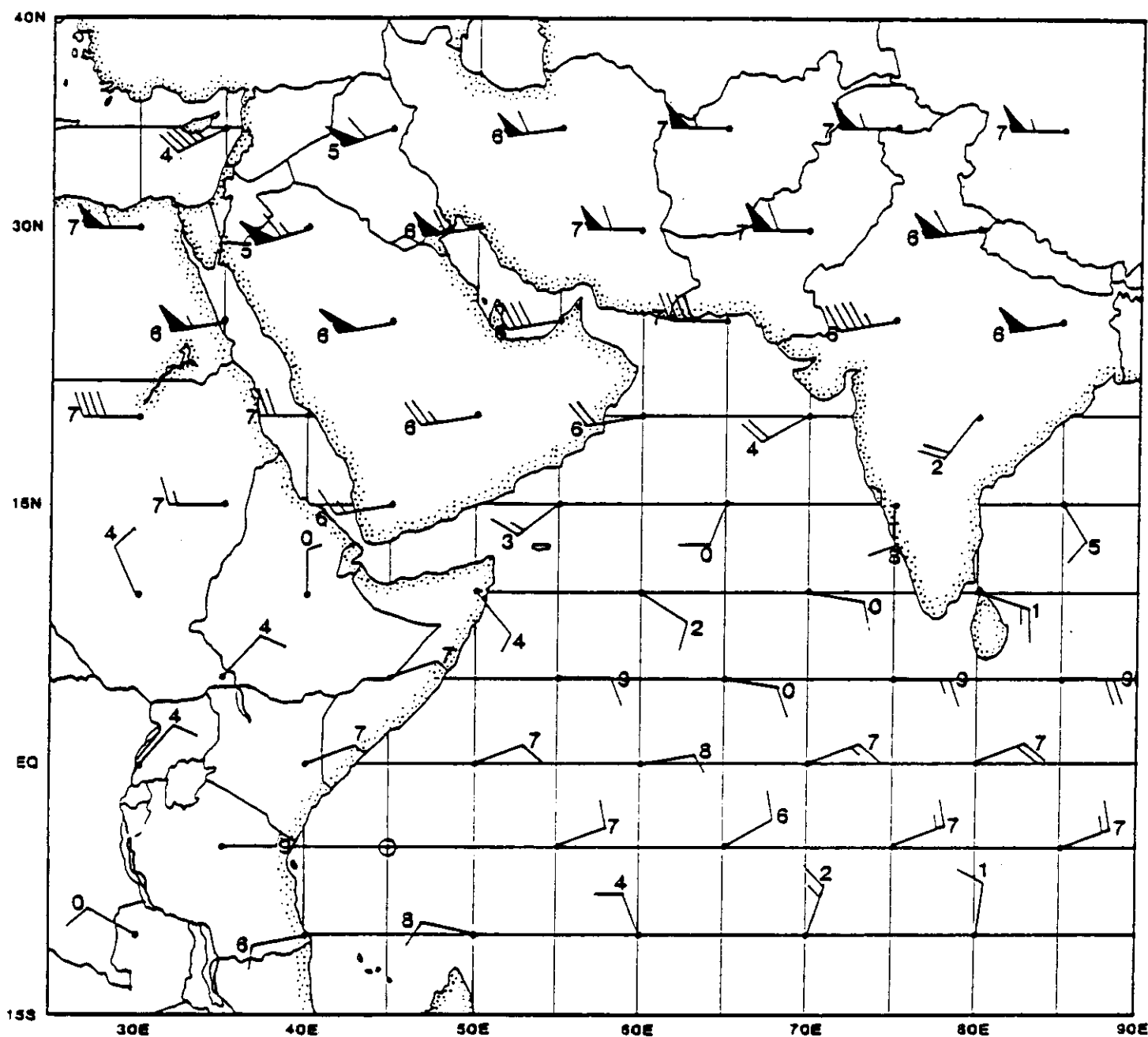


Figure 6-2b. Mean May 200 mb winds (adapted from Sadler, 1975). The numeral by each wind barb is the tens digit of direction. A circle around a latitude-longitude intersection indicates a light, variable wind. Note that westerlies persist over the Asian continent but that the Subtropical Ridge has begun to drift northward from its winter position (near 7°N). Very weak cross-equatorial flow from north to south is shown, and both directional and speed divergence (favorable for tropical cyclone development) is apparent over the Arabian Sea.



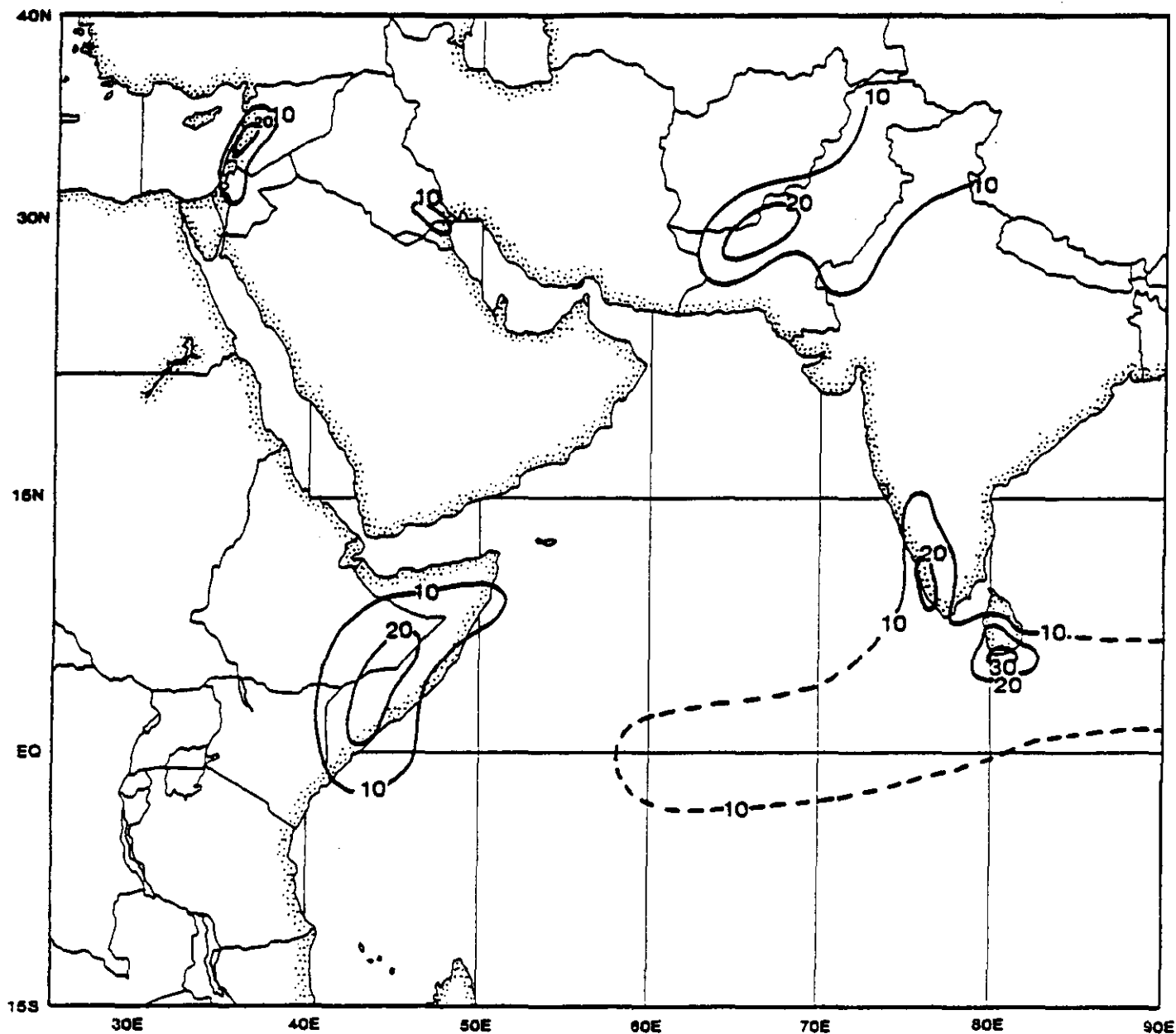


Figure 6-2c. Percent frequency of ceiling less than 1500 ft or visibility less than 3 n mi. The infrequency of adverse weather during this season is apparent in this figure. When significant contours do appear, the reason is usually due to convective rain showers. The area to the west of the southern tip of India is shown as a dashed 10% contour because observations in this region are sparse.



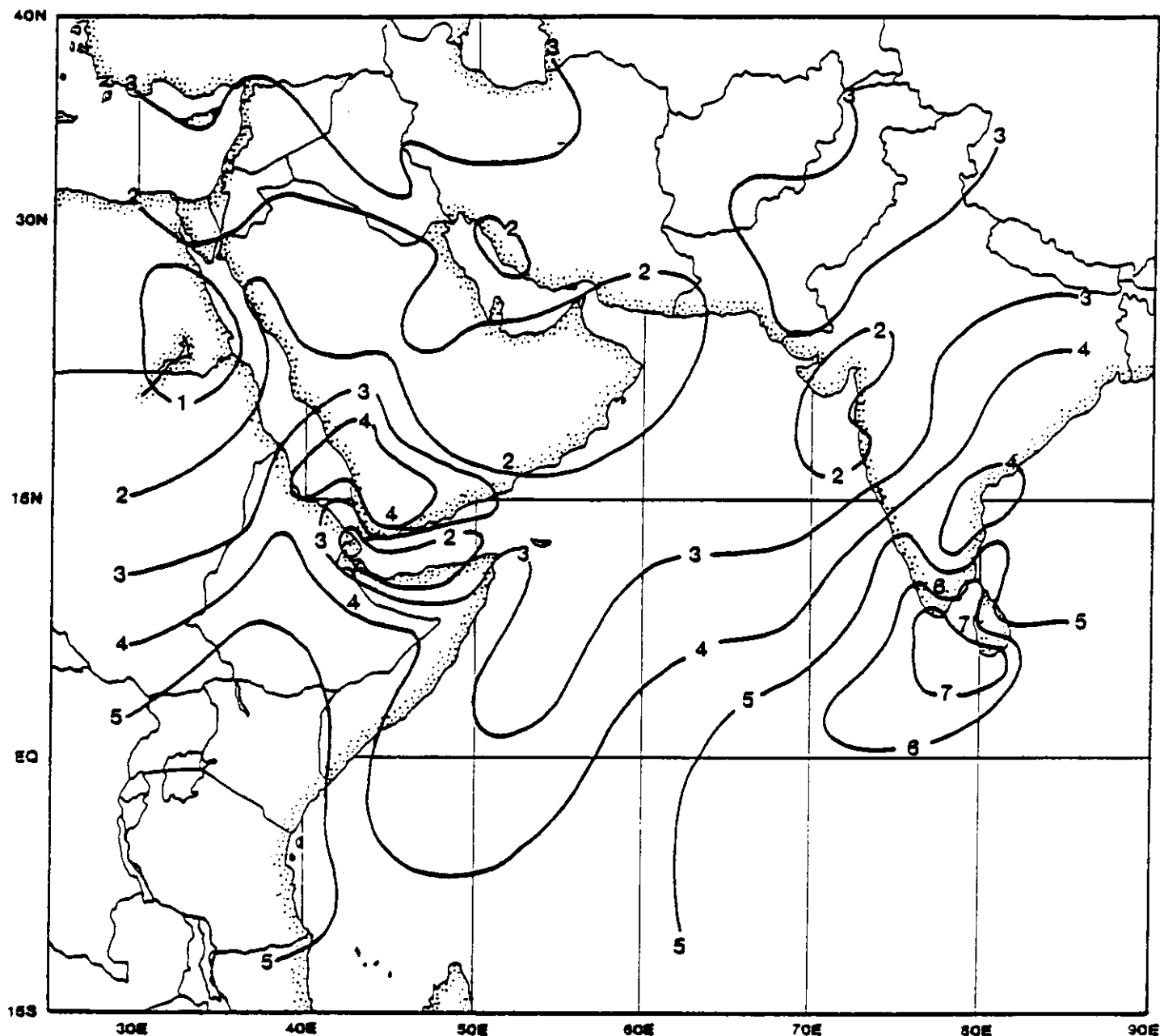


Figure 6-2d. Mean total cloud cover in tenths. The majority of the cloudiness shown is a direct result of convective activity (see Figure 6-2e).



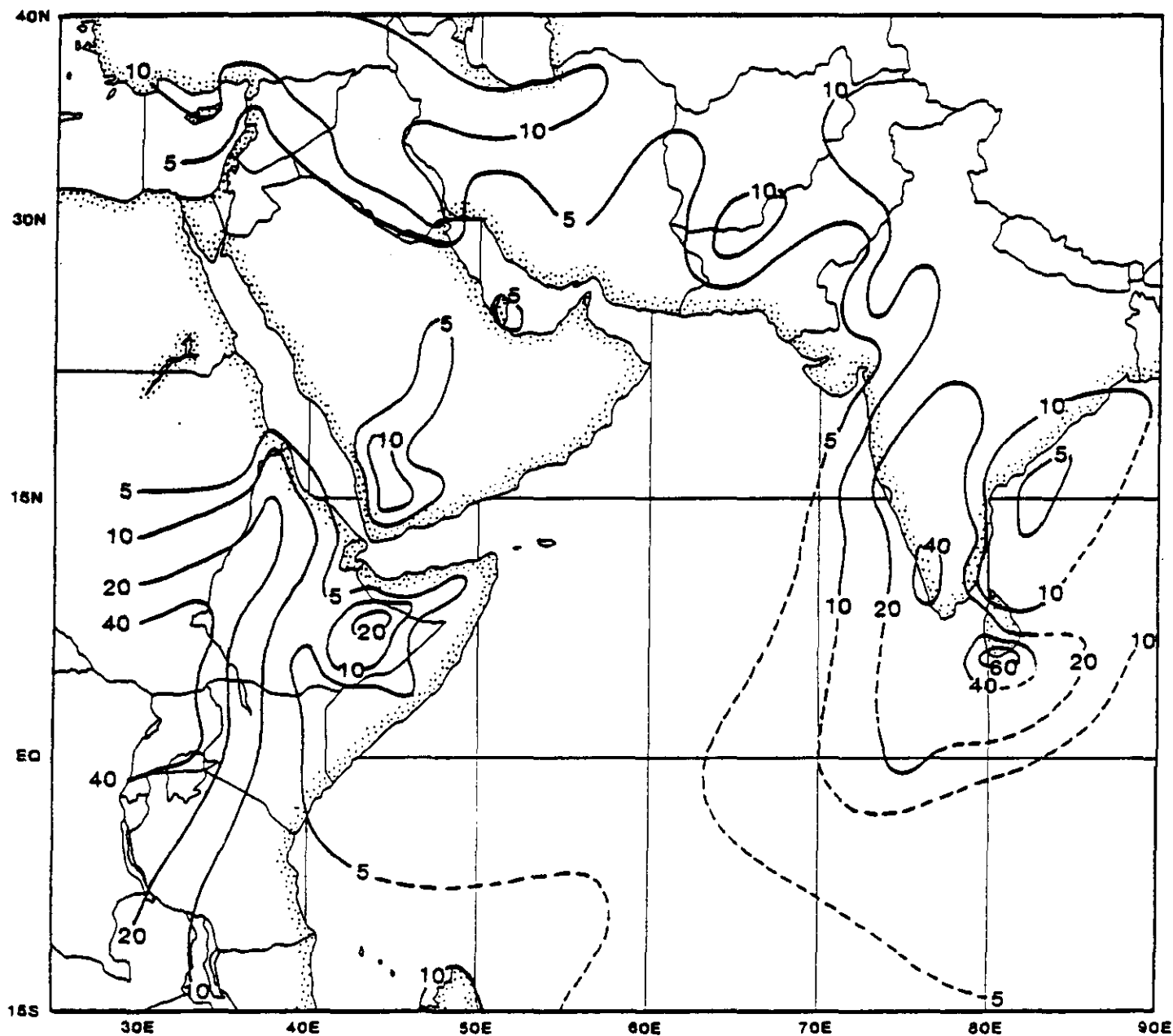


Figure 6-2e. Percent of days with thunderstorms. Light winds and strong heating result in considerable convective activity where high terrain or moist onshore flow creates instability. The thunderstorms of southern India occur primarily at night. Thunderstorm frequency in the tropical Arabian Sea and Bay of Bengal is indicated by dashed contours because the data on which it is based are very sparse.



## 6.2.2 Troughs and Frontal Systems

Although weak cold fronts or troughs continue to pass over the Arabian Peninsula and the Persian Gulf during this season, they are seldom strong enough to penetrate to the Arabian Coast. Figure 6-1 showed an example of an extratropical cloud system moving over the Persian Gulf in late April. Figure 6-3 shows a similar cloud system over the northern Persian Gulf on the last day of May, 1979. It is quite unusual for extratropical disturbances to occur that late in the season in this region.

The weather associated with fronts/troughs during this period is of little consequence except when local squalls are spawned. These squalls can cause moderate to severe sand/dust storms which may affect coastal areas of the Persian Gulf (see Figure 6-2e).

In response to maximum solar insolation, the northern Near-Equatorial Trough intensifies and drifts northward with the sun's nadir. It reaches a mean position near  $10^{\circ}\text{N}$  by late April and provides the conditions favorable for tropical cyclone development. Usually, migration farther northward does not occur smoothly or gradually, but rather, discontinuously; i.e., the Near-Equatorial Trough in the Central Arabian Sea disappears as the Monsoon Trough forms near the northern coastal areas.

## 6.2.3 Large-Scale Cloud and Wind Patterns

### Arabian Sea

The Spring Transition period is one of two periods during which the meridional component of the sea-level pressure gradient reverses direction. During the northern hemisphere winter, relatively low levels of solar radiation result in the maintenance of low-level high pressure ridges over continental areas due to cooling by long wave radiation. As the sun's nadir moves into the Northern Hemisphere during the Spring Transition, incoming short wave radiation exceeds heat loss by long wave radiation. This results in the pressure gradient becoming very weak over the Arabian Sea early in the transition period, then gradually strengthening as the pressure continues to fall over the land areas. The end result is a system of continental heat lows connected by a thermal trough which extends from central India across southern Asia, the Arabian Peninsula and northern Africa.



Figure 6-3. DMSP visual image showing typical cloud conditions late in the Spring Transition period. Features of interest include the convective cell clusters in the area extending southwestward from the southern tip of India. These clusters have formed in the Near-Equatorial Trough. The absence of organization in the cirrus patterns associated with the convective activity reflects the light middle and upper tropospheric wind conditions typical of the transition period. The southern limit of an extratropical disturbance is evident over the northern tip of the Persian Gulf. During the transition period, these systems seldom reach the Arabian Sea. The lighter shaded north-south band in the Central Arabian Sea is sunglint. Since there is little variation in the width of the sunglint pattern, sea conditions (and surface winds) must be relatively uniform throughout the area. Furthermore, the absence of cloud lines implies weak winds. Note that cloud lines are present near the northern African Coast where moderate southwesterly flow is becoming re-established late in the transition period. Instability is apparent over northern India and Pakistan where strong convective cells are occurring in the mountains. The approximate local sun time at the center of this image is 1100 (0653Z).



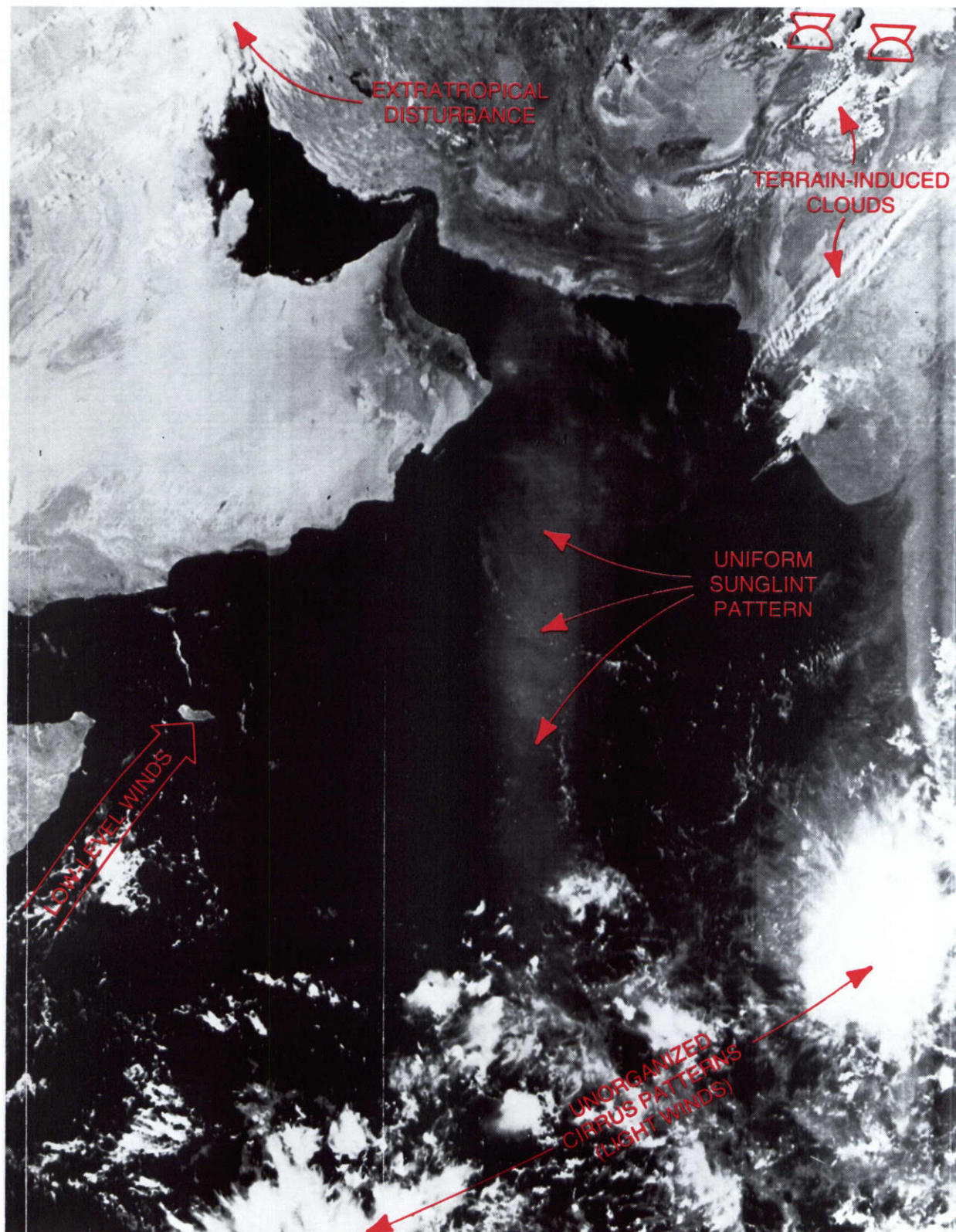


Figure 6-3. DMSP visual image recorded on May 31, 1979 illustrating cloud conditions representative of the end of the Spring Transition period (about 2 weeks prior to the initial surge of the Southwest Monsoon).



The low-level circulation at this time is generally cyclonic around the heat lows but is channeled where terrain restricts flow to one of two approximately opposite directions (e.g., the Red Sea). The trough of low pressure which forms over the surrounding land masses, the strengthening of the high pressure ridge over the Central Arabian Sea and the Coriolis force reversal across the equator result in generally anticyclonic flow over the Arabian Sea. This flow is supported by the Southeast Tradewinds of the Southern Hemisphere which are channeled northward along the east coast of Africa. As this flow crosses the Equator, it is accelerated by the pressure gradient along the African Coast; eventually this process leads to the broad, persistent wind flow of the Southwest Monsoon.

As the season progresses and the effects of the solar heating over southern Asia reaches higher and higher levels, the upper-troposphere Subtropical Ridge migrates northward and strengthens. This results in easterly flow aloft south of the axis of the Subtropical Ridge ( $12^{\circ}$ - $15^{\circ}$ N). Westerlies continue in the portion of the area north of  $15^{\circ}$ N but are weakening rapidly in the area south of  $35^{\circ}$ N (region of Subtropical Jet). The mean upper-troposphere winds are shown in Figure 6-2b.

Weather and winds which result from these large-scale patterns are generally moderate. Early in the period, as the pressure gradient is reversing, winds become light and quite variable, particularly in the north. Cloudiness reaches a minimum due to subsidence which prevails in the area. Coastal wind patterns are largely a result of land/sea breeze effects. Generally, the only heavy weather is associated with convective activity in the Near-Equatorial Trough or with tropical cyclones.

Near the end of the period, southwesterly winds along the African Coast and eastern portion of the Arabian Coast increase markedly. Low-level mixing causes an increase in low cloudiness which often forms in lines roughly parallel to the flow (see area off Somalia in Figure 6-3). Convective activity becomes more common over the southern Indian Coast as atmospheric stability decreases. If a low-level vortex forms in this area, and moves northward along the Indian Coast, the initial surge of the Southwest Monsoon (and the end of the Spring Transition period), can be expected in 3 or 4 days.



### Red Sea and Gulf of Aden

During the Spring Transition period, the changes in the northern Red Sea are mainly related to cloudiness, but in the Gulf of Aden and the southern Red Sea, they are mainly related to the wind flow. Cloud coverage in the north, most of which is caused by extratropical disturbances, gradually diminishes during the transition period as the disturbances become weaker and less likely to penetrate south of the Mediterranean. Increasing air temperature also reduces low-level cloudiness over water areas.

The wind direction reversal usually does not occur in the Gulf of Aden until late May or early June. Winds do become weaker, however, and more subject to land/sea breeze effects. In the Red Sea, the Convergence Zone Cloud Band (CZCB) gradually retreats southward during the period, then disappears as the wind reversal occurs in the Gulf of Aden. Northwest flow follows the retreating CZCB. Gale force winds are rare during this season.

### Persian Gulf and Gulf of Oman

The effects of extratropical disturbances (e.g., cloudiness, southerly winds, etc.) generally disappear in the Persian Gulf during this season. The low-level winds, though quite light, blow more persistently from a northerly direction. Land/Sea breeze effects are apparent, but the strong daytime heating causes the sea breeze to be much stronger and more persistent than the land breeze. This is particularly true along the Iranian coast.

Although light winds and settled weather are the rule, squalls can occur in the western two-thirds of the Persian Gulf. These squalls are accompanied by blowing sand/dust and result from evening thunderstorms (see Figure 6-2e). Tropical cyclones are possible near the eastern approaches to the Gulf of Oman, but are rare.

### India

During the Spring Transition period, most of western India experiences a gradual change from winter to summer conditions. As the heat low develops, onshore wind directions tend to become more common than offshore components.



The resulting increase in moisture in the coastal zone leads to cloud coverage increases and stability decreases. Thunderstorm activity reaches its peak for the year, becoming very common along the southern Indian Coast (see Figure 6-2e). Sea breezes are enhanced and land breezes inhibited by the warmth of the land. Winds are generally weak except near convective activity.

The most significant change is the recurrence of conditions favorable to tropical cyclone formation. Beginning in late April, the incidence of vortex formation off the Indian Coast rises sharply. Convective cloud clusters such as the one near Minicoy Island in Figure 6-3 (lower, right edge) should be watched closely for indications of vortex formation.

#### SPRING TRANSITION FORECAST RULES/AIDS.

- a. The sunglint pattern over the Arabian Sea provides information on relative wind speed; a narrow (in east-west direction) pattern indicates weak surface winds; widening patterns indicate increasing surface winds.
- b. The continental heat lows are very shallow; anticyclonic flow occurs at 850 mb.
- c. Land breezes are very weak and occasionally absent; sea breezes are more persistent than during other seasons.
- d. If southwesterly flow is established along the African Coast, tropical cyclone formation and northward movement along the Indian Coast indicates the end of the transition period and the beginning of the Southwest Monsoon.
- e. Cold, high pressure cells moving into the South Indian Ocean from Africa usually result in a strengthening of the southerly flow along the African Coast.
- f. If extratropical disturbances penetrate to the Arabian Sea late in the period, the transition period will be extended (and the onset of the Southwest Monsoon will be delayed).

#### 6.2.4 Tropical Cyclones

The weakening of the winds (and vertical shear) at all altitudes, the intense solar radiation and the migration of the Near-Equatorial Trough northward to the southern Indian Coast, all lead to a second maximum in the monthly frequencies



of tropical cyclones. According to Sadler, et al. (1973), the probability of a significant tropical cyclone in the Arabian Sea is not substantial for the April-May period (average of one every four years), but a threat does exist and should not be discounted.

According to past records the favored area of formation is centered near  $10^{\circ}\text{N}$ ,  $70^{\circ}\text{E}$ . Favored tracks are generally northwestward toward the Arabian Coast. About 25% of the cyclones move toward the north approximately parallel to the Indian Coast, then recurve and make landfall over northwestern India. In May, the majority of the cyclones cross the Arabian Sea and make landfall along the Arabian Coast. April cyclones usually dissipate or recurve before reaching the Arabian Coast. Only one storm in 80 years of records entered the Gulf of Oman and none were recorded in the Gulf of Aden. (See the discussion of the "Onset Vortex" in Section 3.2.3).

#### Atlantic and Pacific Approaches

Bay of Bengal tropical cyclones are not a threat to ships on a direct route from the Strait of Malacca to the Arabian Sea (see Cumming, 1973, for a discussion of Bay of Bengal weather). In April, tropical cyclones have occurred in the South Indian Ocean between Australia and the Arabian Sea, but the frequency of occurrence is very low. The principal threat occurs in the South Indian Ocean just east of Madagascar during the month of April. Figure 6-4 shows occurrence and movement statistics for the months of April (a) and May (b). Ships on direct routes from either WESTPAC or Diego Garcia to the Atlantic Ocean will more or less parallel the favored track. Appropriate caution should be exercised on any transit of this area prior to early May.

#### TROPICAL CYCLONE FORECAST RULES/AIDS DURING THE SPRING TRANSITION.

- a. Strong convective cloud clusters near  $10^{\circ}\text{N}$ ,  $70^{\circ}\text{E}$  should be watched closely for indications of vortex formation.
- b. If initial movement is toward the northwest, forecast northwest movement to continue.
- c. If initial movement is northward, forecast northward movement to continue with recurvature and landfall near the Kathiawar Peninsula.
- d. In April, northwesterly moving cyclones usually dissipate or recurve northeastward before reaching the Arabian Coast.



# a. April

## TROPICAL STORM TRACKS

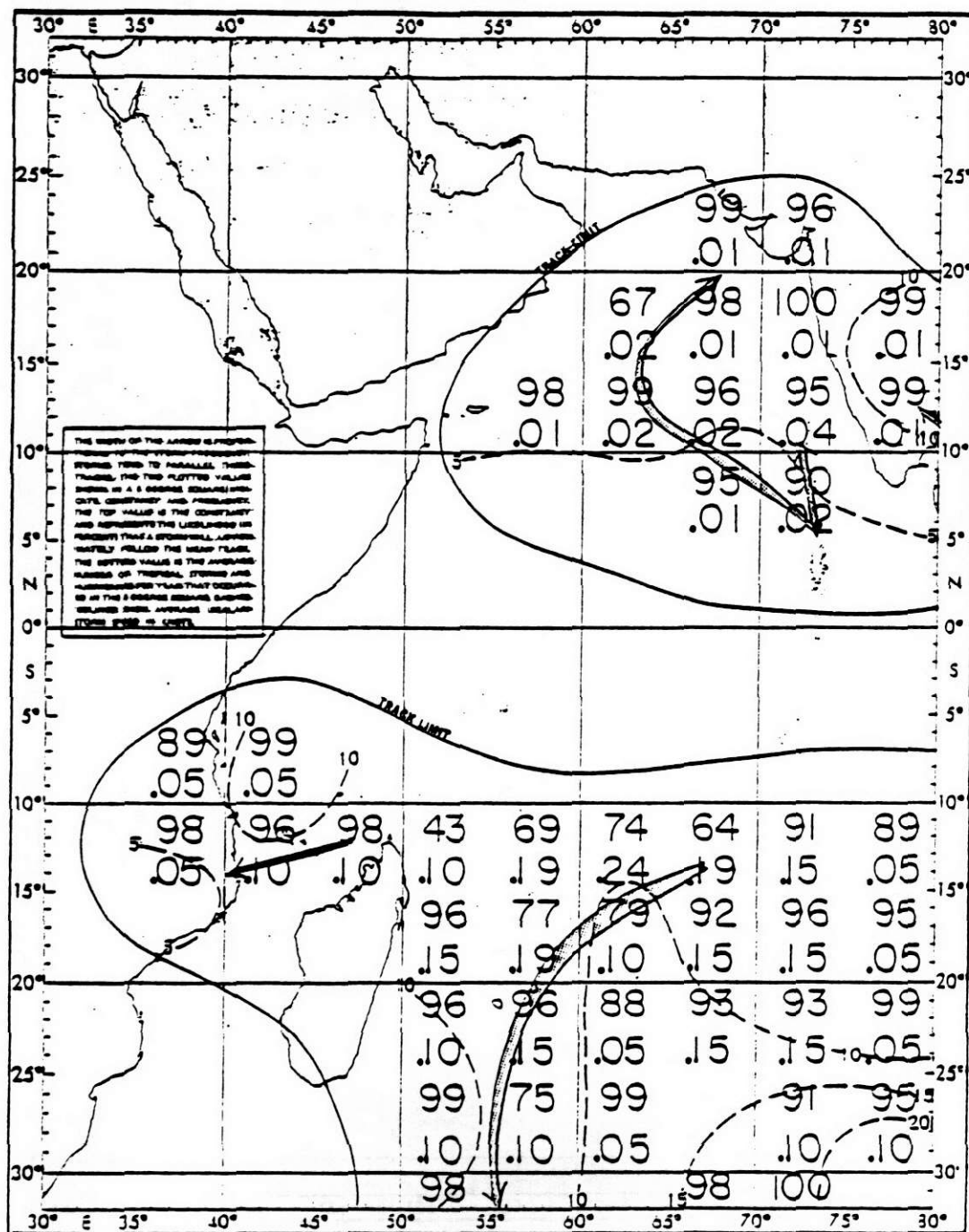


Figure 6-4a. Frequency of occurrence (lower number), probability of movement nearly parallel to the mean track (upper number) and average speed of movement in kt (dashed contours) of tropical cyclones with maximum winds greater than 33 kt (from Naval Weather Service Detachment, Asheville, 1974).



# b. May

## TROPICAL STORM TRACKS

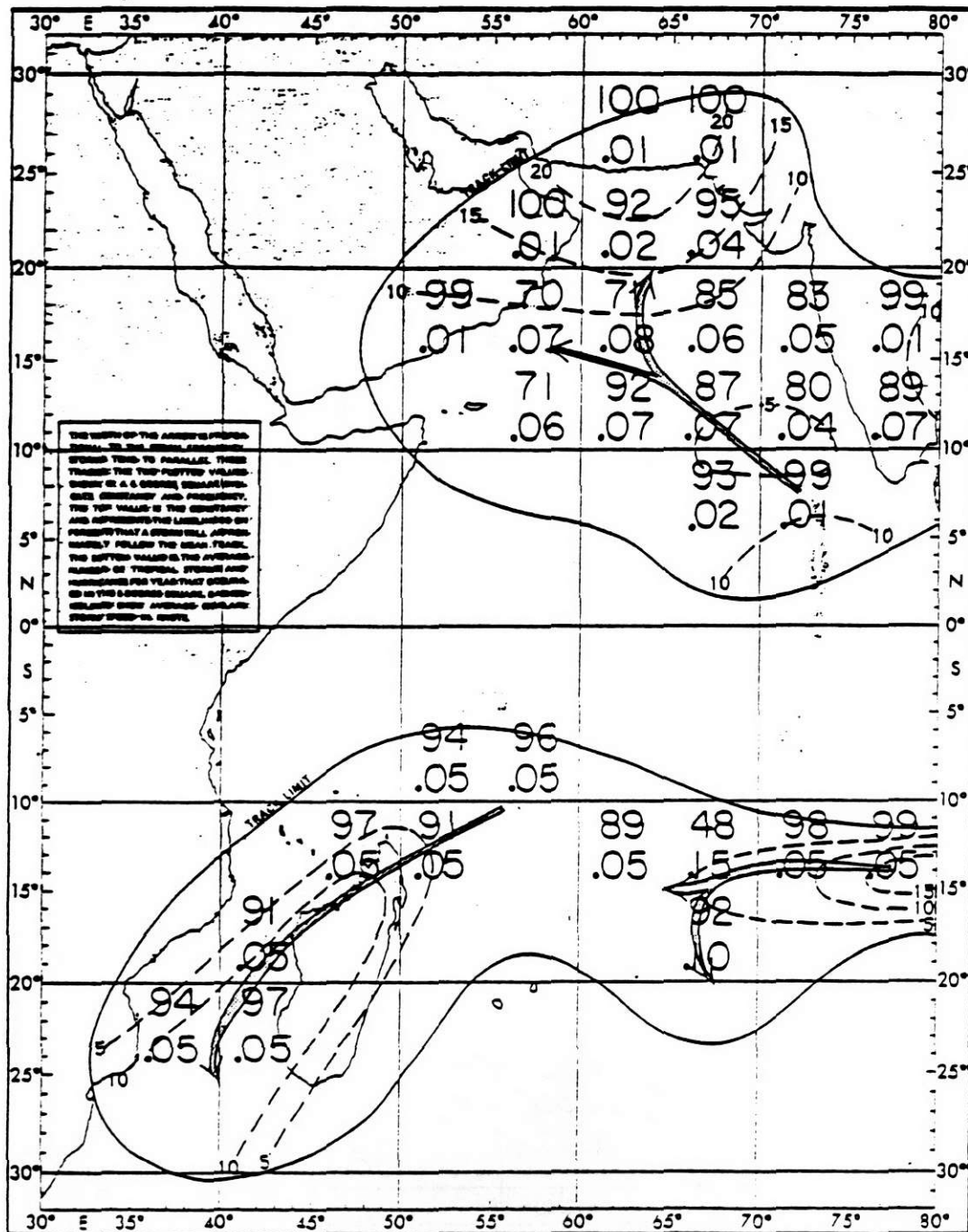


Figure 6-4b. Frequency of occurrence (lower number), probability of movement nearly parallel to the mean track (upper number) and average speed of movement in kt (dashed contours) of tropical cyclones with maximum winds greater than 33 kt (from Naval Weather Service Detachment, Asheville, 1974).